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Seasonal and regional variations of the range of forecast errors of global irradiance by the Japanese operational physical model

Hideaki Ohtake[a], Ken-ichi Shimose[a], Joao Gari da Silva Foncseca Jr. [a]
Takumi Takashima[a], Takashi Oozeki[a], Yoshinori Yamada[b]

a National Institute of Advanced Industrial Science and Technology, OSL, Central 2, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8568, JAPAN
b Meteorological Research Institute, Japan Meteorological Agency, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052, JAPAN

Abstract

For an energy management using large amount of photovoltaic (PV) systems installed in Japan islands, the forecast of a global horizontal irradiance (GHI) based on a numerical weather prediction model (NWP) will be necessary. The Japan meteorological Agency (JMA) has been developed the operational NWP with the horizontal grid spacing of 5km. In this study, the range of forecast errors of GHI values obtained from the NWP are investigated. Seasonal changes of forecast errors and the dependency on the weather conditions using surface-measured GHI data are researched during the period from 2008 to 2011.

Results of the validation of hourly GHI forecasts for a station showed that overestimations in relatively higher clearness index (CI) (slightly cloudy weather) were found while underestimations in relatively lower CI (cloudy weather) were found. On the other hands, ranges of forecast errors in the clear sky or the deep cloudy conditions tend to be relatively small. From seasonal changes of the range of forecast errors, it was found that underestimations of GHI in summer tended to be significant. Annual changes of the range of forecast errors were not large during the period. In order to estimate the effect of decreasing forecast errors by the spatial-averaging method, we also analyzed forecast errors of GHI values for the relatively large area in the Kanto region (near Tokyo), located in central Japan. Compared the ranges of forecast errors by the point analysis for Tsukuba station with those for the relatively large area, the ranges of forecast errors by the spatial-averaging method were decreased up to about 70 % compared with the range of a point analysis for Tsukuba station.

Keywords: GHI; PV forecast; physical model; forecast errors; seasonal changes; annual changes; regional changes

* Corresponding author Hideaki Ohtake. Tel.: +81 029-849-1526; fax: +81 029-861-5829.
*E-mail address:*hideaki-ootake@aist.go.jp.

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1. Introduction

For a management of power supply using large amount of photovoltaic (PV) energy, both an accurate forecast of the PV power production and forecast errors are necessary, because the PV power production is significantly affected by spatial and temporal variations of global horizontal irradiance (GHI) [1]. To forecast the PV power production, outputs of meteorological parameters from a numerical weather prediction model (NWP) based on a physical model are often used [2][3]. However, the GHI forecasts obtained from the NWP have certainly errors. Confidence intervals of the GHI forecast values estimated from the forecast errors are also useful information for the energy management.

In Japan, the Japan meteorological Agency (JMA) has been developed the operational NWP of a mesoscale model (MSM) with the horizontal grid spacing of 5km. JMA investigated characteristics of forecast errors of the downward shortwave radiation (i.e., same as the GHI), suggested that critical underestimations of GHI forecasts in summer [4]. Ohtake et al. (2012) [5] also investigated that forecast errors of the GHI of MSM for each JMA station in the Kanto region located in the central part of Japan main islands (near Tokyo), indicated that seasonal variations of forecast errors: underestimations (overestimations) in summer (winter). Regional characteristics of forecast errors were also researched by the previous study [6].

Seasonal characteristics of forecast errors of the GHI forecasts values (i.e., an estimation of confidence intervals) obtained from MSM have not been enough in previous studies. At first, ranges of forecast errors are investigated on seasonal and annual changes in this study. In addition, a smoothing effect by a spatial-averaging method is also investigated.

2. Data and Model descriptions

To validate the forecasted GHI values in this study, surface-observed GHI were measured by pyranometers (Kipp & Zonen CM3) at the Tokyo, Choshi, Utsunomiya, Maebashi and Kofu stations (at the JMA observational stations in the Kanto region) in the period from 2008 to 2011. Both a pyrheliometer (Kipp & Zonen CH1 (CHP1 from 31 Aug, 2011)) and the pyranometer of Kipp & Zonen CM21 (CMP22 from the same time) are also installed at the Tsukuba station.

The JMA has been developed the operational NWP of MSM with the horizontal grid spacing of 5km [7]. The MSM include various processes (dynamics, clouds, rain and/or snowfall, aerosol, radiation, ocean, sea ice etc.). The interactions during each process are included in order to express various meteorological phenomena. In MSM, the forecast of the GHI values is mainly based on both the radiation (shortwave process, abbreviated by “SW” shown in Fig.1) and microphysical processes. GHI values are outputted in the intervals of one hour, although the forecasts are conducted at the intervals of the 15 minutes. Since relatively large time integration of GHI forecast of 33 hours is conducted four times a day. These products obtained from MSM could be possible to take advantage of the planning of the energy management for a one-day ahead. Both the description and the model setting of MSM are described in the previous study (Ohtake et al. 2012) [5].

A target area analyzed in this paper is the Kanto region on the central Japan (near Tokyo), shown by the blues color region in Fig. 2. In this area, the power supply has been received by the Tokyo Electric Company (TEPCO). This region is surrounded by mountains from the northward to the westward directions while this region is also surrounded by the Pacific Ocean from the eastward to the southward directions. The six surface observational stations of the JMA described above are shown by the red squares in Fig. 2.

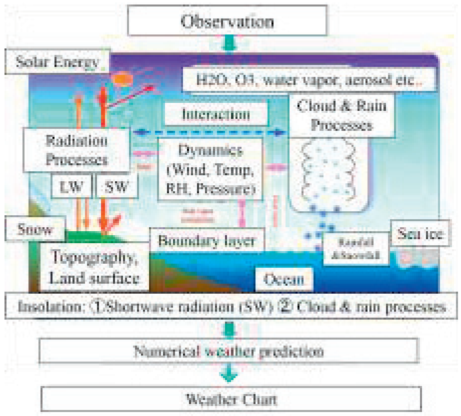

Fig.1. Schematic image of the description of numerical weather forecasting model is shown. "LW" and "SW" in the radiation process mean the long wave radiation and short wave radiation processes, respectively.

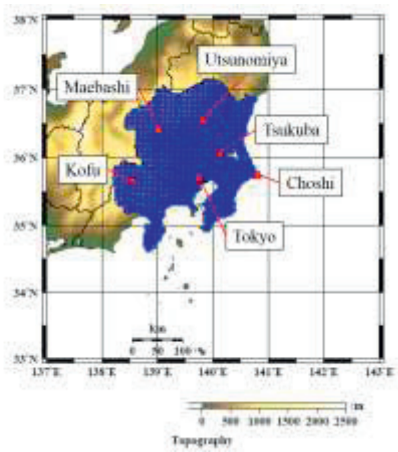

Fig .2 The map for the Kanto region and the topography whose scale is shown in the bottom. The blue dots and the six red squares mean the MSM model grids and the surface observational stations of JMA for the target region analyzed in this study, respectively.

3. Ranges of forecast errors of GHI values

3.1 Forecast errors of GHI values

Firstly, we validated the hourly-forecasted GHI values obtained from the MSM of JMA using the surface observed GHI values at a single site. Figure 3 shows a comparison between the forecasts and the observations of GHI values at Tsukuba station, located in an inland area in the Kanto region (see Fig. 2), for 2011. Generally, the GHI forecasts tend to be close to the one to one line, suggesting that the GHI forecasts from the MSM are well forecasted as a whole. However, relative large forecast errors of GHI values are also often found. Each color means scatter plots at every month. GHI forecasts in summer tend to be underestimated compared with surface-observed GHI values. The correlation efficiency at June, which is a rainy season in Japan, is the worst (r=0.85). On the other hand, correlation efficiencies in the period from autumn to spring tend to be large.

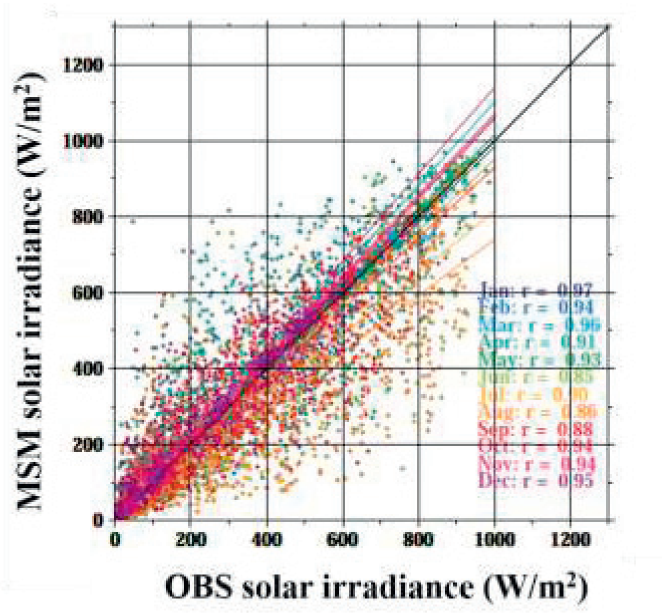

Fig. 3 The relationship between the hourly-observed solar irradiance (global horizontal irradiance; GHI) and the hourly-forecasted GHI on each season (color plots) at Tsukuba station for 2011. The solid lines and the "r" values at each color mean fitted lines and correlation efficiencies at each month, respectively.

We also estimated the forecast errors at Tsukuba station for 2011 using two evaluation parameters; mean bias errors (MBE) and root mean square errors (RMSE). Both MBE and RMSE values are calculated based on the suface observed GHI values. MBE values ranges from -100.5 W/m^2 to 44.5 W/m^2. In summer, MSM GHI values tend to underestimated significantly compared to surface-observed GHI values. On the other seasons, relatively positive biases of GHI forecasts are found. RMSE values ranges from 50.5 W/m^2 to 182.5 W/m^2. Similar seasonal variations of both MBE and RMSE values are found in the previous three years during 2008 to 2010 (see Table 1 of Ohtake 2012 [5]).

Table.1 Monthly MBE and RMSE values of the GHI forecasts at Tsukuba station for 2011.

Tsukuba 2011	MBE	RMSE (W/m^2)
JAN	-7.8	50.5
FEB	9.2	86.2
MAR	24.8	87.2
APR	44.5	137.7
MAY	8.2	118.4
JUN	-18.6	156.8
JLY	-78.5	152.7
AUG	-100.5	182.5
SEP	-27	132.9
OCT	14.7	81.9
NOV	13.3	69.6
DEC	30.7	68.5

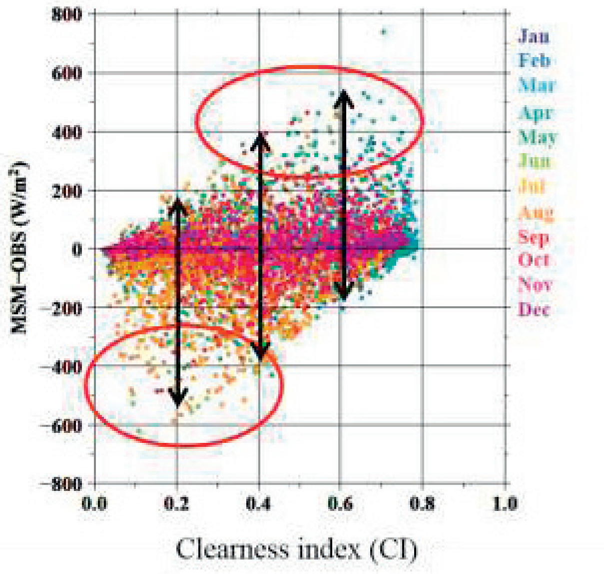

Fig. 4 The relationship between the hourly-forecasted clearness indices (CI; horizontal axis) and the forecast errors (forecasts – observations; MSM-OBS: vertical axis) at Tsukuba station on each season for 2011.

Next, we investigated the relationship between the weather conditions and forecast errors of GHI values. Here, we used the clearness index (CI) as an indicator of the weather conditions. In this paper, CI is defined the normalized GHI values divided by the extraterrestrial solar irradiance calculated theoretically at every hour. Figure 4 shows the relationship between hourly CI forecasts and forecast errors of GHI values based on the Fig. 3. This figure shows forecast errors are relyed on the CI clearly; relatively high CI ($0.5 < CI < 0.7$, corresponds to slightly cloudy weather conditions) has positive forecast errors, while relative small CI ($0.1 < CI < 0.3$, corresponds to deep cloudy weather conditions) has negative forecast errors. These results means that the model tend to forecast optically thick clouds in summer and forecast optically thin clouds in winter, respectively. For CI~0.4, forecast errors of GHI values range from -400 to 400 W/m^2 (negative or positive forecast errors). The ranges of forecast errors for other weather conditions (CI>0.4 or < 0.4) is also similar to that of CI~0.4. Results from this figure suggested that forecast errors of the GHI values obtained from MSM were clearly depended on the weather conditions.

3.2 Seasonal variations

Seasonal changes of the range of forecast errors of GHI values are investigated in this subsection. Figure 5 shows the relationship between forecasted CI values and ranges of forecast errors at Tsukuba station at each month for 2011. The boxes and errors bars mean the data of 90 % of GHI forecast errors and the maximum or minimum values at each forecasted CI for each month, respectively (see left axis). Black solid lines at each panel mean an appearance frequency at every CI analysed for each month (see right axis). In winter (December through March), the number of the relative higher CI (> 0.6, slightly cloudy weather) is relatively large. From spring to summer (April through August), the distribution of frequency changes: the frequency of relative lower CI (< 0.3, cloudy weather) gradually increase. In autumn, the frequency of higher CI increases again.

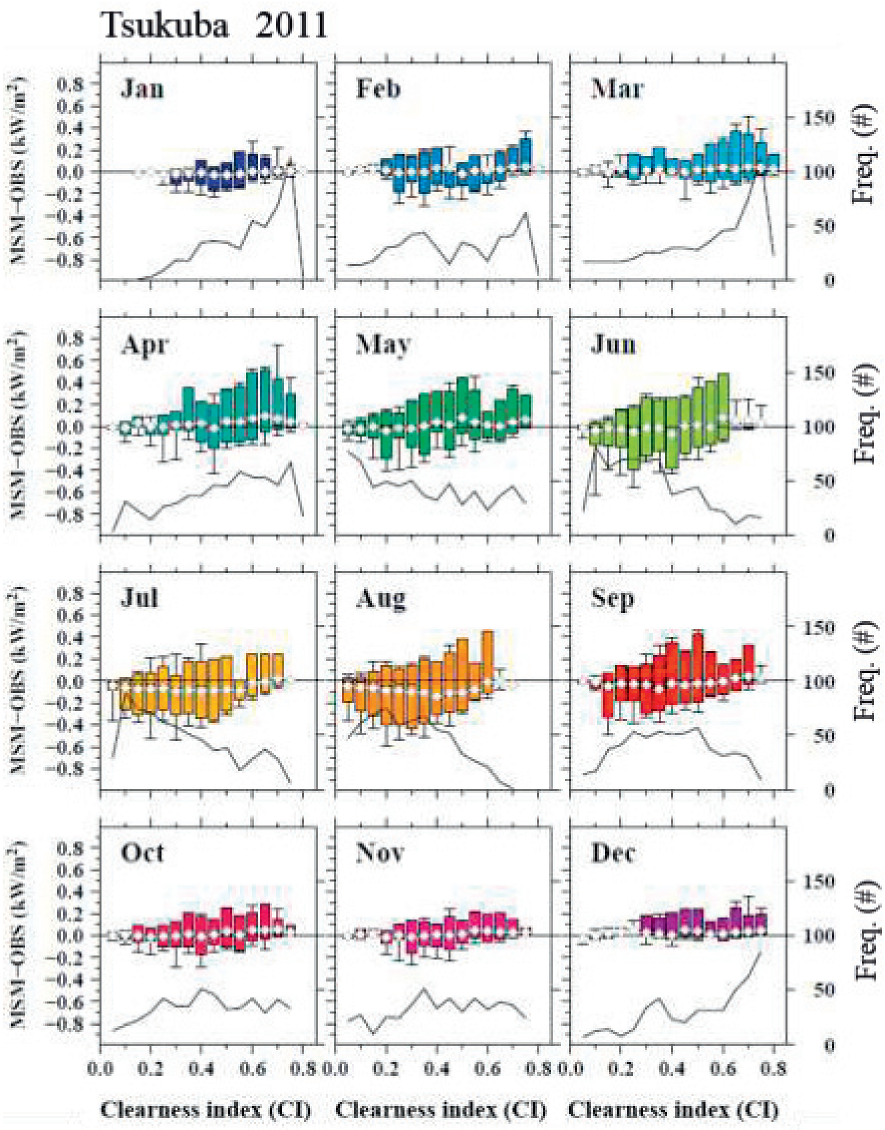

Fig. 5 Monthly changes of the range of forecast errors (forecasts – observations; MSM-OBS: vertical axis (left axis)) of the GHI at every forecasted clearness indices (CI; horizontal axis) at the Tsukuba station for 2011. The box plots accounted for the data of 90 % of GHI forecasts at each CI. The bar plots indicate the maximum and minimum values of the forecast errors. Appearance frequency of data analyzed at each hourly-forecasted CI is shown by solid lines at each panel (right axis).

Ranges of forecast errors of the GHI forecasts has seasonal variations; relatively large ranges in summers because of large solar irradiance in summers. In winter and early summer (from December to June), ranges of forecast errors of GHI in relatively large CI conditions (slightly cloudy weather) are large and the forecasts tend to be overestimated. On the other hand, ranges in the summer (July and August) for relatively small CI conditions (cloudy weather) are also large. Generally, the GHI forecasts in summer tend to be systematically underestimated.

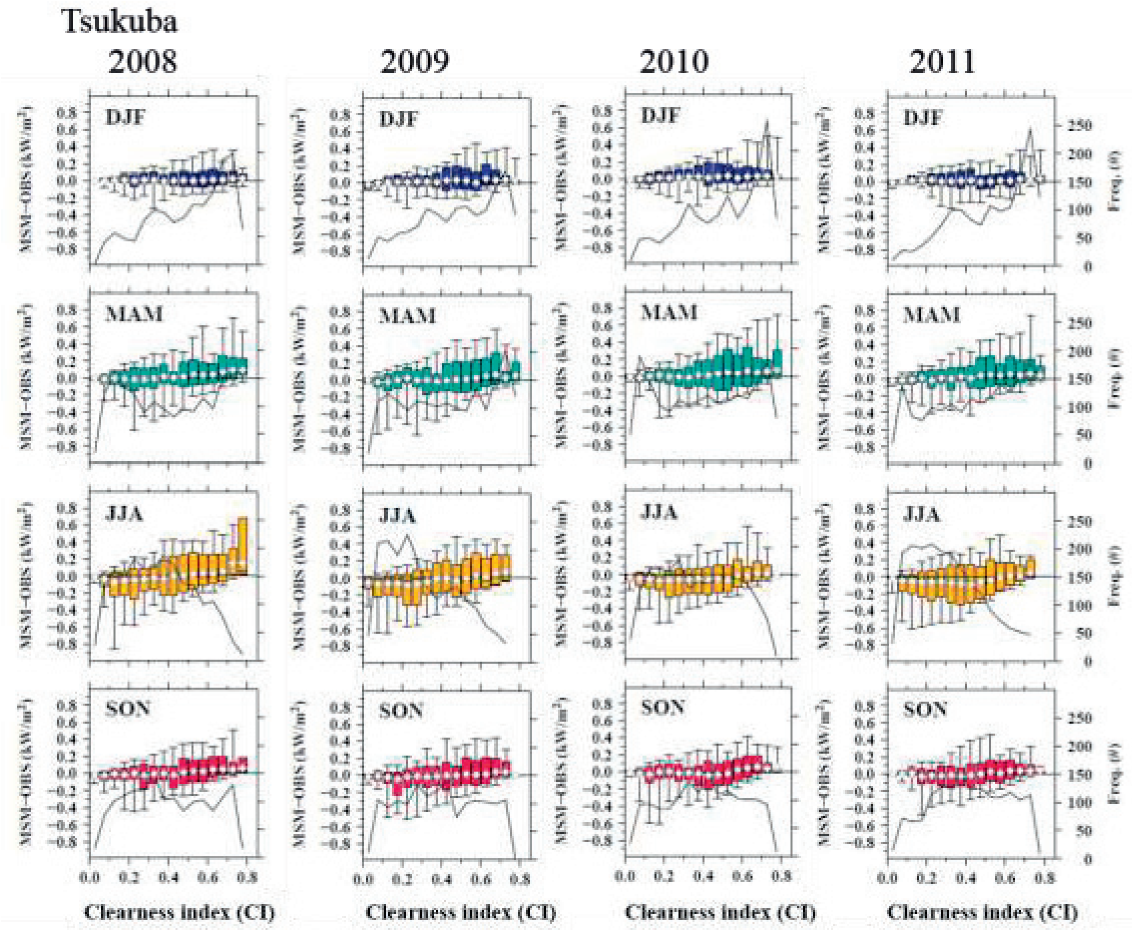

Fig. 6 Annual and seasonal changes of the range of forecast errors (forecasts – observations; MSM-OBS) of the GHI (left axis) at every forecasted clearness indices (CI) at the Tsukuba station for 2011. Each season are divided into winter (December to February; DJF), spring (March to May), summer (June to August) and autumn (September to November), respectively. Appearance frequency of hourly-forecasted CI are shown by solid line at each panel (right axis).

To understand annual and seasonal changes of the range of forecast errors, comparisons of the forecast errors in the four years (from 2008 to 2011) are also made for Tsukuba station (Fig. 6). Patterns of the range of forecast errors at each season tend to be similar to those of each year. Therefore, annual changes are not large. From the results, the GHI values obtained from the MSM of JMA tend to include such systematic forecast errors which have seasonal characteristics and depended on the weather conditions (i.e., clearness indices).

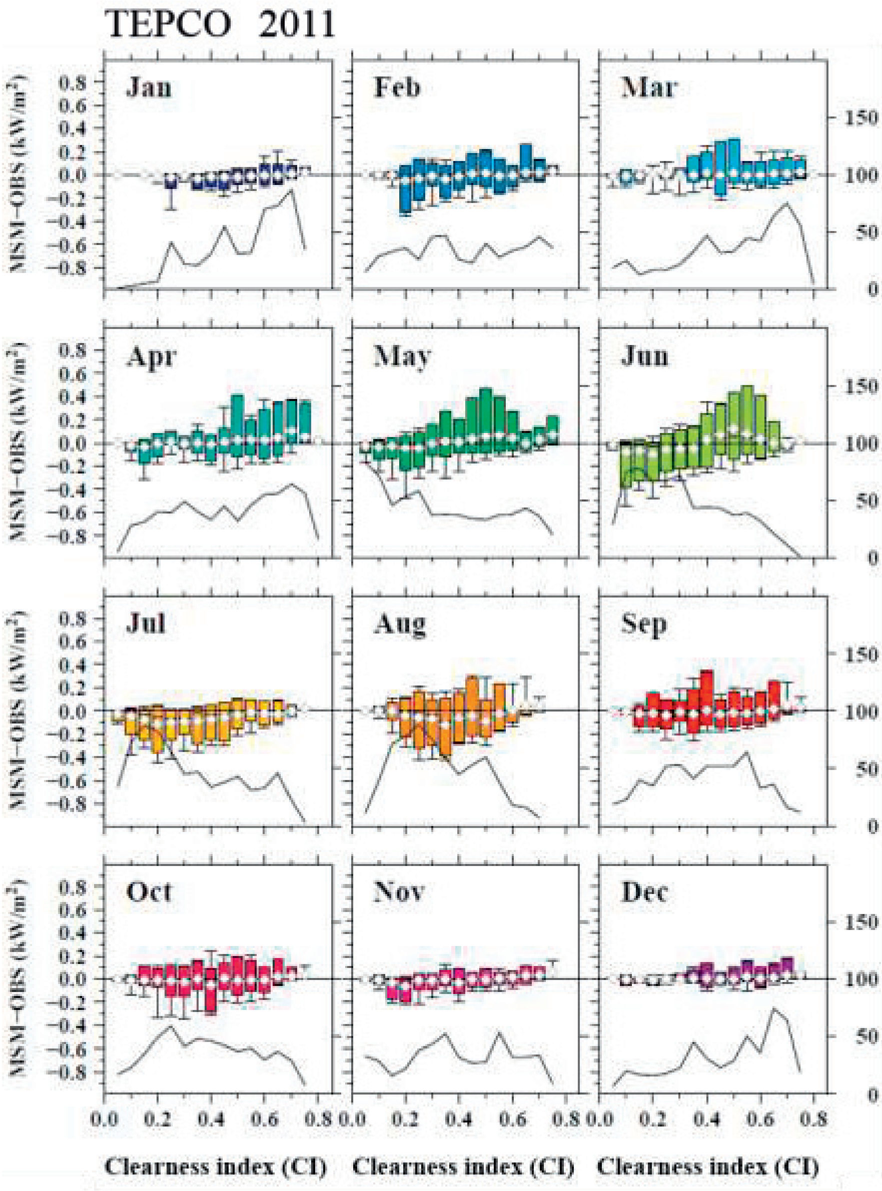

Fig. 7 As in Fig. 5, but for the relatively large area on the Kanto region (see Fig. 2) for 2011.

3.3 The effect of spatial-averaging within a target region

In order to investigate the range of forecast errors of GHI values for the relatively large area, we averaged forecasted GHI values spatially for the target region in the Kanto region (a total of 1478 of blue grids shown in Fig. 2). Similarly, observed GHI values for the six JMA stations (red squares shown in Fig. 2; Tokyo, Tsukuba, Utsunomiya, Maebashi, Choshi and Kofu) are also averaged. Here, we simply averaged forecasted GHI values or observational GHI values within the target region, since the information of the locations of both small PV systems over residential buildings and large PV (i.e., mega-solar) systems (that is, the density of the PV power production), are not considered. This results suggested that the decrease of ranges were found in a whole season (Fig. 7) compared with those results of the point analysis for Tsukuba station at each month (see Fig. 5).

Although spatial and temporal changes of the GHI values are horizontally smoothed by the effect of the spatial-averaging method, monthly patterns of the relationship between the CI conditions and forecast errors are also found. Results for the other three years (from 2008 to 2010) are generally similar to the results for 2011. Ranges of forecast errors of GHI values are helpful parameters in order to estimate the reliability of the GHI forecasts. Considering the planning of the energy management including other energy supplies (e.g., hydroelectric power generation, pumping up generation etc.), reduced ranges of forecast errors of the GHI values by the smoothing effect would be useful to decrease the extra cost of energy resources (the fuel to run the thermal power generation equipment, which would be used to reduce temporal variations of the PV power generation).

4. Summary

In this paper, forecast errors of the GHI obtained from MSM of JMA and seasonal changes of the ranges of forecast errors were investigated. In addition, the smoothing effect by a spatial-averaging method of the GHI values for the Kanto region, which located in central Japan, was studied.

Seasonal changes of forecast errors showed that underestimations of GHI were significant in summer. Annual changes of forecast errors were not large during the four years from 2008 to 2011. Ranges of forecast errors of the GHI values spatial-averaged within the target (Kanto) region were generally decreased up to about 70 % compared with results for Tsukuba station (i.e., point analysis).

Validation results of hourly forecasts of the GHI showed that overestimations of GHI forecasts were found in relatively higher CI ($0.5 < CI < 0.7$) conditions while underestimations of those were also found in relatively lower CI ($0.1 < CI < 0.3$) conditions. In the high or low CI values (near CI $\sim$ 0.0 or 0.8), ranges of forecast errors tend to be small, suggesting that the GHI values from MSM are well forecasted in clear sky or deep cloudy (or rainy) conditions.

To perform the stable operation of the energy supply with large PV power generation and other power generations, accurate forecast values of the GHI are desired. However, forecast values have errors invariably. Thus, the improvement of cloud-radiation processes of MSM for more accurate forecast of GHI values is basically required [8]. On the other hand, the range of forecast errors (that is, confidence intervals of GHI forecasts) could be also useful information for the management of energy supply including the large amount of PV systems. Both the GHI forecasts as such and the confidence intervals by the spatial-averaging method are useful to reduce an extra cost of energy resources (the fuel to run the thermal power generation equipment).

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